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LEAST SQUARES IMAGE MATCHING IN A REAL TIME PHOTOGRAMMETRIC STATION

Leif Haajanen
Helsinki University of Technology
Institute of Photogrammetry and Remote Sensing
Helsinki, Finland

Abstract

The identification and locating of the corresponding points in convergent images is a common problem in real-time photogrammetric stations. The use of least squares image matching to solve this problem is described. The performance of a photogrammetric station is improved by reducing the computational cost of least squares image matching.

1. Introduction

A real-time photogrammetric (RTP) station is an automatic system which performs three dimensional (3-D) measurements in real-time/3/. A RTP station usually consists of multiple CCD-cameras producing a standard video signal which is digitized by an image-processing board /7/. In order to obtain correct results, the RTP station is calibrated /2/, /5/. To be able to compute the 3-D coordinates of the object to be measured, the inner and outer orientations of all cameras must be known. These parameters are determined in the set-up calibration. Additionally, the image coordinates of the corresponding points in different camera images have to be measured. Then the 3-D coordinates are computed by the intersection of the rays coming from all camera projection centers and going through the corresponding image coordinates. The least squares image matching is used to determine the corresponding image coordinates.

The least squares image matching (LSIM) is presented in Chapter 2. The computational cost of the traditional LSIM is quite high because of the amount of iterative computation per pixel performed in LSIM. In Chapter 3 some methods to reduce the computational cost of LSIM are described. In the last Chapter some conclusions are made and further development is discussed.

2. Least squares image matching

The purpose of image matching is to find the location of a given pattern, called target image, from another image, the search image. The image matching can be done with several techniques, but in a RTP station the least squares method is best, because it gives a subpixel accuracy and it is fast enough.

The least squares method is based on the minimization of squared residuals. The least squares criterion can be written

$$\Sigma v^2 = \min$$

where the sum in the case of image matching consists of all pixels in the target image and v's are the differences between the target image pixel intensities and the corresponding search image pixel intensities. Because of the repeatability of the measurement /6/, the simple functional model used in this case is

$$g_1(x,y) = g_2(x-x_0 , y-y_0) + e$$

where g_1 is the greyvalue function of the target image, g_2 is the greyvalue function of the search image, x and y are the image coordinates of target image, x_0 and y_0 are the shifts between the target and search images, and e is the noise.

As we can see, this model is non-linear and the linearized form of the functional model is

$$g_1(x,y)=g_2(x^0,y^0)-(\partial g_2(x^0,y^0)/\partial x)dx-(\partial g_2(x^0,y^0)/\partial y)dy+e$$

where dx and dy are the corrections in x and y direction, and x^0 and y^0 are the current approximate values. As the first derivative of the image function g_2 with respect to both x and y is required, the approximations

$$\partial g_2(x^0,y^0)/\partial x = g_1(x+1) - g_1(x-1)$$
$$\partial g_2(x^0,y^0)/\partial y = g_1(y+1) - g_1(y-1)$$

are used. The search image function is approximated by the target image instead of the search image /4/. The use of the target image as the search image function gives us a way to reduce the computational cost, as can be seen in next Chapter.

The algorithm of LSIM can be described by the following steps:

Step 1: Compute the x- and y-gradient images of the target image.
Step 2: Form the constant left hand side of the normal equations.

Step 3: Compute new grey values for the shifted search image using bilinear interpolation by floating point arithmetics.
Step 4: Form the right hand side of the normal equations and the squared sum of the residuals.
Step 5: Solve the x- and y-shifts.
Step 6: If the terminating conditions are true, terminate iteration, else goto step 3.

This iterative algorithm needs good approximate starting values to converge. These values are obtained from the teaching procedure in which the template images for targets are assigned /4/.

3. Reducing computational cost of LSIM

The first reduction of computational cost comes up from the use of target image instead of search image to approximate the first derivative of the search image function. The computational efficiency will be improved, as the design matrix now is constant, so only the right hand side of the normal equations has to be recomputed between iteration steps.

Most of the remaining computational cost is coming from the bilinear interpolation (step 3). We know that the computation of the bilinear interpolation takes 11 floating point operations per pixel. Usually, we use a target image consisting of 31*31 pixels and from experience we know that the average number of iteration rounds is about 10. Under these circumstances the number of floating point operations is 105710. By reducing the size of the target image, the computation can be reduced, but this is not always possible.

If we look at the linearized formula of LSIM we can see that the design matrix is totally dependent on the gradients. This means that small gradients are affecting the computation less than greater gradients. Usually, in industrial applications, target image contains a great number of small gradients and only a few big gradients. This gives us a way to reduce the computational cost. The reduction is done during the first iteration steps by using only those pixels which correspond to the greatest gradient values. The final matching is done by using the whole information. If we are using ten percents of the gradients and we know from experience that we need on average eight iterations using the reduced data, and only two using the whole data, we see that the number of needed floating point operations in our example is reduced to 29590. As we can see, the computational cost is reduced about 72 percent. There are still means for further reduction in the number of iteration rounds needed in the computation.

If we take a closer look to the behaviour of the solution vector in the course of iteration, we can see that it usually has right direction but it is too short. This gives us an indication that simply by multiplicating the solution vector with a suitable constant, the number of needed iteration rounds can be reduced. According to the example, reduction is 50 percent using constant value 1.9, meaning that totally only five iteration steps are needed. From these five only one is using the whole information. This means that the number of floating point operations needed in the bilinear interpolation is reduced to 14795. In the example the reduction of the computational cost is reduced from the original by 86 percent.

4. Conclusions

The implementation of the LSIM in a RTP station has opened a variety of new potential applications. All kinds of tasks in process control and robot guidance are now possible due to the fact that no physical targetting is needed. Although these applications are important, the most important application made possible by the LSIM is the stability control of a RTP station. After the setup calibration /5/ where the 3-D coordinate system is determined, the station can now maintain this coordinate system by continously measuring stable control points with the help of LSIM. These control points should always give the same image coordinates. If this is not the case, the calibration can be updated according to these measurements /1/.

The speed and repeatability are two very important qualities of a RTP station. To get an idea about the performance of LSIM in this respect, let us take an example. The LSIM has been implemented into the Mapvision /7/ measuring system, which is running with Intel 386/387 processors. In a four-camera installation, Mapvision is able to measure four points in five seconds using LSIM. The measuring time is of course dependent on the amount of displacement of each point to be measured from the default location. The repeatability of the LSIM in the Mapvision system has generally varied between 0.1 to 0.02 pixels.

The major problem in the current implementation of the LSIM is its sensitiveness to lighting conditions. In order to handle this problem, radiometric correction parameters will be included in the functional model of LSIM. This should make the LSIM insensitive for radiometric changes in the measuring site. Another problem is the small pull in range. This pull in range is dependent on the size of the target. The pull in range is usually equal to the size of the target if the target is symmetric. If the symmetric target used is small, the pull in range of LSIM will be small. The pull in range is subject for further development. One possible solution could be a method where the target information is spread over a larger area in the search image during the first iteration rounds.

The least squares image matching was presented and some methods to decrease the computational cost was outlined. Due to the computational reduction the Mapvision measuring system, consisting of off-the-shelf components only, can be considered as a real-time photogrammetric system also without active targetting.

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